

CHARACTERIZING INDOOR AIRFLOW AND POLLUTANT TRANSPORT USING SIMULATION MODELING FOR PROTOTYPICAL BUILDINGS. 1. OFFICE BUILDINGS

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ABSTRACT

This paper describes the first efforts at developing a set of prototypical buildings defined to capture the key features affecting airflow and pollutant transport in buildings. These buildings will be used to model airflow and pollutant transport for emergency response scenarios when limited site-specific information is available and immediate decisions must be made, and to better understand key features of buildings controlling occupant exposures to indoor pollutant sources. This paper presents an example of this approach for a prototypical intermediate-sized, open style, commercial building. Interzonal transport due to a short-term source release, e.g., accidental chemical spill, in the bottom and the upper floors is predicted and corresponding HVAC system operation effects and potential responses are considered. Three-hour average exposure estimates are used to compare effects of source location and HVAC operation.

INTRODUCTION AND MOTIVATION

Buildings are constructed and operated in many different ways. Unfortunately, this complexity makes understanding and predicting a building's air flow and pollutant transport patterns a site-by-site evaluation process. However, in the event of a hazardous pollutant release in or near a building, decisions must be made quickly with little or no information on how the pollutant is likely to be distributed within the specific building. For example, a cleaning solvent spill in an office building's printing shop can result in a sudden chemical release that can result in exposures to occupants in other parts of the building. Unfortunately, emergency response personnel must make appropriate decisions despite the limited information about the building and its operating conditions. One approach to providing useful information for these responders and building operators is to model airflow and pollutant transport on a set of prototypical buildings defined to capture key features of the building stock. The prototypical buildings can then be used to evaluate possible pollutant release scenarios and identify possible responses prior to such an event. The simulations can also be used to train the first-responders and building managers to react to similar incidents and to identify information that should be gathered prior to and during an incident. This approach can also be used to more quantitatively understand key building features affecting the transport of indoor pollutants in multizone buildings. The purpose of this paper is to demonstrate this approach and provide examples of effects of source location and HVAC operation and of possible responses. Specifically, the paper describes an intermediate-sized prototypical office building, the results of simulations for two pollutant release locations and

three HVAC system operations, and their implications for emergency response and for pre-planning mitigation measures.

METHODS

In defining prototypical office buildings, we first considered the features of office buildings most important for determining transport and fate of a released toxic agent. These include floor heights, number of floors, floor plan layout (e.g., open plan versus closed individual rooms), HVAC system layout and operation, size and number of shafts (e.g., elevator and utility), and leakage between zones. Many of the parameters defined for prototypical office buildings were selected using the EPA Building Assessment Survey and Evaluation (BASE) study database [1]. The BASE database includes responses to questionnaires and experimental monitoring data to assess current indoor air quality in large commercial office buildings. As of this date, 70 U.S. buildings, from 10 regions across the United States, have been sampled and additional buildings are in the process of being investigated. A summary of the information for the first 40 buildings is provided in Table 1. Additional information about the sampling procedures, questionnaires, and new/updated data are available at <http://www.epa.gov/iedweb00/base/base.html>.

Table 1 Summary statistics (arithmetic averages) for office buildings in BASE study database.

| Classification | No. of Buildings | No. of Floors Above Grade | Gross Floor Area (m ²) | Occupancy (m ² /person) | Ceiling Height (m ²) |
|----------------|------------------|---------------------------|------------------------------------|------------------------------------|----------------------------------|
| High Rise | 13 | 19 | 49,500 | 27 | 2.7 |
| Interm. Rise | 23 | 5 | 22,000 | 28 | 2.7 |
| Low Rise | 5 | 2 | 8,700 | 14 | 2.9 |

The prototypical building used in the simulation and analysis procedure was an intermediate-sized, open-style, five-floor, commercial building with a total floor area of 22,000 m² (see Table 1 and Figure 1). The open style floor plan is characterized by a single central zone that is surrounded by zones along its perimeter. The central well-mixed zone represents office and conference spaces, hallways, and general interior building area which are all believed to exhibit reasonably similar building flow conditions. Connected to this zone are perimeter facade zones that represent office spaces facing the exterior windows. A facade zone encompasses all of the offices on a perimeter wing since they are believed to exhibit similar flow communication with the outside and the interior. A small zone located within the central zone represents the elevators, stairs, and utility shafts and is connected to adjoining floors to represent the stairwell/shaft system.

The COMIS multizone flow and pollutant transport model [2] was applied to the prototypical building to predict and evaluate pollutant transport from possible release scenarios and alternative responses. Flow characteristics for each zone were estimated by summing the number of doors, cracks, and windows likely in each room that is characterized by the well-mixed zone and estimating representative parameters for the flow and transport modeling from data compiled by Lidament [3] to represent a moderately tight building. Since the purpose of this approach is to understand the general trends of the inter-zone and inter-floor flows representative of typical flow patterns in this size and style of building, only general estimates of flow and transport parameters are used and do not represent the actual flow in a specific building. Hence, not all specific parameters for the modeling are presented here.

However as an estimate of the overall building tightness, 7.2 air changes per hour (ACH) are predicted if the building was pressurized to 50 Pa (≈ 0.36 ACH normalized leakage).

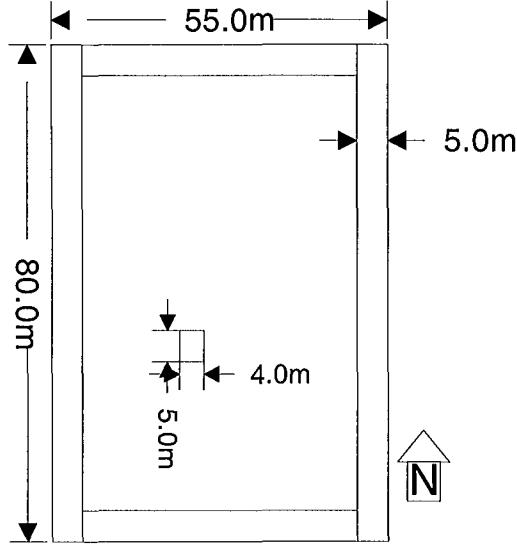


Figure 1: Open-style floor plan for a five-floor prototypical office building. The temperature of each zone is 20°C; the outside temperature is 15°C. Wind blows from the west at 3 m/s. The floor plan is identical for each floor. The HVAC unit is located on the roof of the building with a single air handler supplying each floor and zone.

Two scenarios were considered, release of a pollutant in the central zone of the (1) first and the (2) fifth floor for ten minutes at 1 g/s. The incident could represent a chemical spill, e.g., ammonia from a spill of cleaning solution that volatilizes but is quickly contained or intermittent emissions from a malfunctioning photocopier. The pollutant transport was predicted under three alternative HVAC operating conditions: (1) no HVAC operation, (2) HVAC with 100% air recirculation at 4 building ACH, and (3) HVAC with no air recirculation at 4 ACH (i.e., once-through ventilation). A general HVAC system layout was assumed at this stage of the analysis, i.e., a single air handler located on the roof that serves all of the floors (and zones) with complete mixing of outlet and return air.

RESULTS AND DISCUSSION

Figures 2 and 3 illustrate the pollutant transport in the central zone of the first and fifth floors for a source release in the first floor and the fifth floor, respectively. The zones adjacent to the central zone on a given floor exhibited approximately 30% lower concentrations but with similar time-series profiles.

Table 2 summarizes the three-hour time-averaged exposure (concentration x time) to building occupants in the central zone of the first and fifth floors. The average exposure is used to compare the differences in exposure from the alternative HVAC operating conditions. In both source release scenarios, as expected, the exposure for occupants in both the first and fifth floors is least with the HVAC system operating with no recirculated air. Contaminated air is removed from the building and is replaced by outside air. Hence, under this open-style building configuration, HVAC system operation with no recirculated air reduces the exposure regardless of the location of the source.

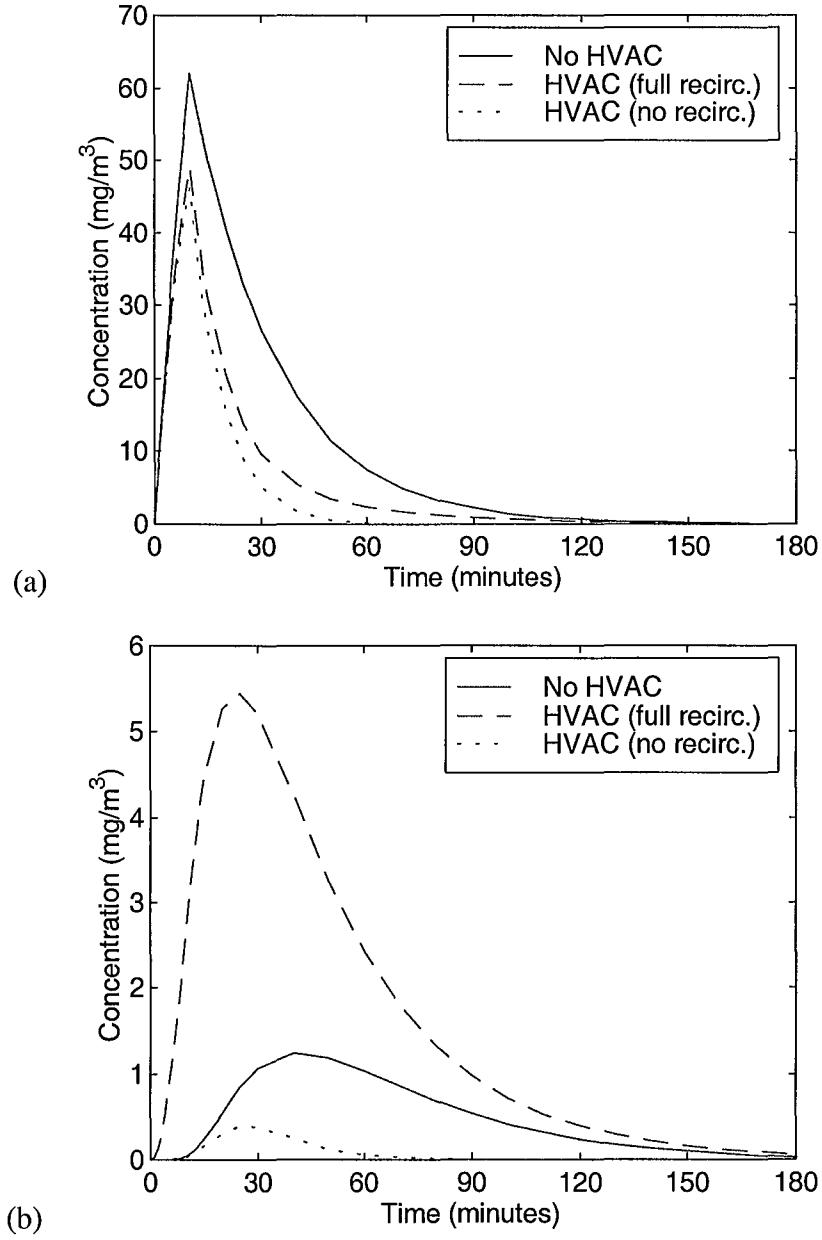


Figure 2: Predicted concentration profiles in the central zones of the first (a) and fifth (b) floors from a pollutant released in the central zone of the first floor. The pollutant is released for ten minutes at 1 g/s. Note that the scale for concentration differs by a factor of ≈ 10 between the two figures.

If the HVAC system is recirculating some of the indoor air, and/or a switch-over to all outside air requires a considerable amount of time, then an alternative decision between shutting down the HVAC system or continuing to run with air recirculation must be made. With the HVAC system not operating, the pollutant mass is slowly transported to the other zones and floors such that exposure is high in the source zone and much less elsewhere. However, if the HVAC unit operates with recirculated air, the mass of the pollutant is more quickly dispersed in the building but will dilute the building wide average concentration. Hence lower exposure is observed in the source zone and higher exposure is observed elsewhere than without HVAC operation. These results suggest that the toxicity of the pollutant released may dictate the

Table 2: Summary of source scenarios, alternative HVAC operating conditions, and corresponding three-hour exposure estimates. The source locations are in the central zone of the indicated floor and HVAC operation is at 4 ACH.

| Source Location | Scenario | Exposure (mg-min/m ³) | |
|-----------------|--------------------|-----------------------------------|-------------|
| | | First Floor | Fifth Floor |
| First floor | None | 1600 | 80 |
| " " | Full recirculation | 890 | 280 |
| " " | No recirculation | 640 | 10 |
| Fifth floor | None | 0 | 1900 |
| " " | Full recirculation | 250 | 950 |
| " " | No Recirculation | 0 | 670 |

CONCLUSIONS

The prototypical buildings will be used as a base framework for understanding pollutant transport through buildings and for evaluating possible emergency responses and control options. The example presented here illustrates the approach and indicates the general scope of the work. In subsequent work, efforts will be made to better characterize the link between building operation, environmental conditions, and exposure. In addition, the prototypical building development will also assist in identifying and quantifying other features of a building that are not well known to affect the air flow and pollutant transport by comparing the effects on transport and exposure if various building features are adjusted. Hence a fully characterized prototypical building system will provide a baseline by which other systems or operations can be compared.

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